

REVIEW ARTICLE

Pharmacological Properties and Therapeutic Applications of *Acalypha indica*



Vijayalakshmi MK^{*1}, Hamsini Eisha E², Sheron Kevin S², Selvakumar V², Ashwini A², Venkateshwaran S²

¹Associate Professor, Department of Pharmaceutical Chemistry, Faculty of Pharmacy, Bharath Institute of Higher Education and Research, Chennai, Tamil Nadu, India

²UG Scholar, Faculty of Pharmacy, Bharath Institute of Higher Education and Research, Selaiyur, Chennai, Tamil Nadu, India

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Abstract: *Acalypha indica*, a medicinal plant native to tropical and subtropical regions, has significant value in traditional medicine systems across Asia and Africa. The plant contains various bioactive compounds including alkaloids, flavonoids, tannins, and saponins that contribute to its therapeutic properties. Modern pharmacological studies show its potential in treating various ailments through antibacterial, anti-inflammatory, antioxidant, anticancer, antidiabetic, and wound-healing activities. The plant's leaves, roots, and aerial parts exhibit prominent biological effects, with the leaves showing particular potential in antimicrobial and anti-inflammatory applications. Recent investigations have shown mechanisms of action for several therapeutic properties, including prostaglandin-mediated analgesic effects and cytokine-modulated wound healing. Clinical studies indicate potential applications in managing diabetes, skin conditions, and respiratory disorders. While traditional uses are extensively studied, standardization of extracts and detailed toxicological profiling remain areas requiring further research. Modern analytical techniques have identified key compounds like acalyphamide and acalyphine, providing molecular information about the plant's biological activities. This review presents current evidence on pharmacological properties, phytochemical composition, and therapeutic applications of *A. indica*.

Keywords: *Acalypha indica*; Medicinal Plants; Phytochemicals; Pharmacological Activities; Traditional Medicine.

1. Introduction

Medicinal plants remain vital contributors to global healthcare, with increasing scientific validation supporting their traditional applications. *Acalypha indica*, belongs to the family Euphorbiaceae, is a significant medicinal plant species with documented therapeutic properties [1]. The plant has been integral to traditional medical systems including Ayurveda, Siddha, and various African healing practices [2]. *A. indica* typically grows as an annual herb reaching heights of 0.5-1.5 meters, characterized by ovate-lanceolate leaves and small, inconspicuous flowers [3]. Its distribution spans tropical and subtropical regions, with notable presence in India, Sri Lanka, Pakistan, and parts of Africa [4]. The plant thrives in diverse habitats, from disturbed areas to agricultural landscapes, contributing to its widespread availability [5].



Figure 1. Leaves of *A. indica*

* Corresponding author: Vijayalakshmi MK

Many studies have identified multiple bioactive compounds in *A. indica*, including alkaloids, flavonoids, tannins, and terpenoids [6]. These compounds show various pharmacological activities, supporting the plant's traditional applications in treating respiratory ailments, skin disorders, and gastrointestinal conditions [7]. Recent studies have particularly focused on its antibacterial, anti-inflammatory, and antioxidant properties [8]. The rising interest in natural medicine alternatives has sparked renewed investigation into *A. indica*'s therapeutic potential. Advanced analytical techniques have enabled detailed characterization of its chemical constituents, while improved experimental methodologies have provided deeper insights into its mechanisms of action [9, 10].

2. Botanical description

2.1. Taxonomic Classification

A. indica belongs to the genus *Acalypha*, which includes approximately 450 species. It belongs to the family of Euphorbiaceae, order Malpighiales, class Magnoliopsida, and kingdom Plantae [11].

2.2. Morphological Features

2.2.1. Vegetative Characteristics

The plant develops a well-branched root system with a woody stem appearing approximately 30 days after germination. The taproot system is extensive, penetrating up to 30-40 cm in soil depth, with numerous lateral roots enhancing nutrient absorption and soil stabilization [12]. The stem is erect, herbaceous, and grows to a height of 30-75 cm, occasionally reaching up to 1.5 meters under favorable conditions. It exhibits distinctive angular branching patterns with green to reddish-purple coloration, and young stems show characteristic pubescence that diminishes with maturity [13].

The leaves exhibit distinctive characteristics: they are alternately arranged, thin, and broadly ovate to ovate-lanceolate, measuring 3-8 cm in length and 2-5 cm in width. The leaf margins display serrated edges, while the surface shows sparse to moderate pubescence. The leaves are characterized by a reticulate venation pattern with 5-7 primary veins radiating from the base. The adaxial surface is dark green, while the abaxial surface appears lighter, with prominent venation. Petioles are slender, measuring 2-6 cm in length, and show a slight groove on the upper surface. Young leaves often show a bronze or reddish tinge, particularly along the margins and veins [14].

2.2.2. Reproductive Structures

The inflorescence consists of axillary spikes bearing both male and female flowers, showing a monoecious reproductive system. Female flowers are characterized by distinctive bracts measuring 6-8 mm, while male flowers appear as small, greenish clusters. The male flowers are positioned in the upper portion of the spike, typically measuring 1-2 mm in diameter, with 4-5 stamens and yellow anthers. Female flowers occupy the lower portion of the spike and are characterized by three deeply divided styles, each approximately 3-4 mm long, with distinctive red coloration [15].

The flowering period typically extends from early summer through late autumn, with peak flowering observed during the rainy season. The fruit develops as a small capsule containing seeds with a smooth testa. The capsules are three-lobed, measuring 2-3 mm in diameter, and exhibit a characteristic explosive dehiscence mechanism when mature. Each capsule contains three seeds, which are ovoid to subglobose, measuring approximately 1.5-2 mm in length. The seeds display a smooth, dark brown to black testa with a small caruncle, and show remarkable viability even under adverse storage conditions [16]. The reproductive cycle from flower initiation to seed maturity typically spans 4-6 weeks, with environmental factors significantly influencing the timing and success of reproduction. Under optimal conditions, a single plant can produce several hundred seeds throughout its reproductive phase, contributing to its successful establishment in various ecological niches [17].

3. Phytochemical Composition

3.1. Major Chemical Constituents

The chemical profile of *A. indica* reveals diverse compounds contributing to its biological activities. Primary constituents include:

3.1.1. Alkaloids

Acalyphine serves as the principal alkaloid, accompanied by triacetoneamine derivatives. These compounds show significant pharmacological effects, particularly in neurological and antimicrobial applications. Acalyphine, a cyanogenic pyridine alkaloid, is predominantly concentrated in the root system and exhibits dose-dependent biological activities. It consists of a pyridine ring system

with a cyanogenic side chain, contributing to its stability and bioactivity. The triacetoneamine derivatives, characterized by their tricyclic structure, are distributed throughout the plant tissues but show higher concentrations in mature leaves and stem bark. These alkaloids demonstrate variable polarity and solubility characteristics, which influence their extraction efficiency and bioavailability [18].

The biosynthetic pathway of these alkaloids involves the condensation of acetone units and subsequent incorporation of nitrogen, leading to the formation of the characteristic ring structures. The concentration of these alkaloids varies seasonally, with peak levels observed during the flowering phase. Environmental stressors, including drought and pest attacks, can significantly influence alkaloid production, often resulting in elevated concentrations. The plant's alkaloid profile also shows regional variations, with specimens from different geographical locations exhibiting quantitative differences in alkaloid content while maintaining qualitative consistency in the major compounds [19]. The structural characteristics of these alkaloids, particularly the presence of reactive nitrogen groups and conjugated systems, contribute to their ability to interact with various biological targets.

Table 1. Major Phytochemical Constituents of *Acalypha indica*

Class of Compounds	Representative Compounds	Plant Part	Reported Benefits
Alkaloids	Acalyphin, Acalyphine	Leaves, Roots	Antimicrobial, Anti-inflammatory
Flavonoids	Quercetin, Kaempferol	Leaves	Antioxidant, Anti-inflammatory
Tannins	Various polyphenols	Stem, Leaves	Wound healing, Antimicrobial
Steroids	β -sitosterol	Roots, Seeds	Anti-inflammatory
Glycosides	Various saponins	Whole plant	Various therapeutic effects

3.1.2. Flavonoids and Phenolics

Multiple flavonoid compounds occur in the leaves and aerial parts, including quercetin derivatives and kaempferol glycosides [20]. These compounds contribute substantially to the plant's antioxidant properties [21]. The quercetin derivatives predominantly exist as 3-O-glycosides and 7-O-glycosides, with varying sugar moieties including glucose, rhamnose, and rutinose. The kaempferol glycosides demonstrate structural diversity through different glycosylation patterns, particularly at the C-3 and C-7 positions. Additional phenolic compounds include caffeic acid derivatives, p-coumaric acid, and various hydroxycinnamic acid conjugates. These compounds exhibit synergistic effects in free radical scavenging and metal ion chelation, enhancing the overall antioxidant capacity of the plant extracts [20, 21].

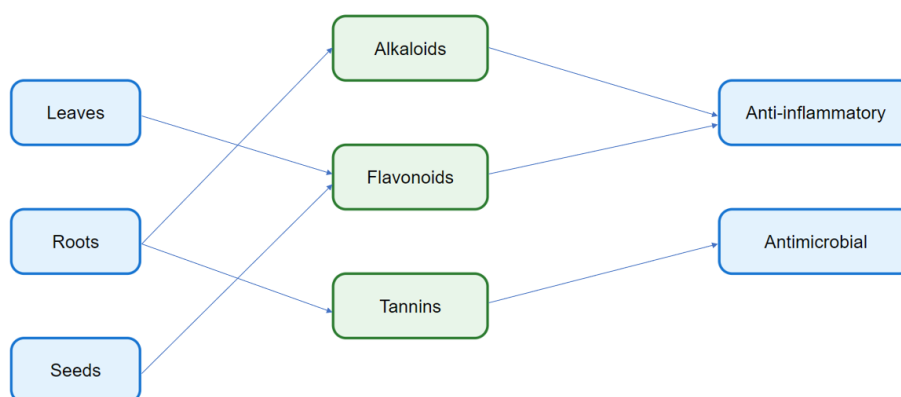


Figure 2. Phytochemical Components and Their Distribution in *A. indica*

3.1.3. Terpenoids and Saponins

The root system contains several terpenoid compounds, notably acalyphin and related structures [22]. Saponins, present primarily in root tissues, demonstrate significant biological activities including membrane-disrupting properties [23]. The terpenoid profile includes both mono- and sesquiterpenes, with acalyphin representing a unique diterpenoid structure characteristic of the genus. These compounds feature complex cyclic systems with various degrees of oxidation and hydroxylation. The saponin fraction consists primarily of triterpenoid saponins with diverse glycosylation patterns, contributing to their amphipathic nature

3.2. Distribution of Bioactive Compounds

Different plant parts exhibit distinct phytochemical profiles. Leaves contain the highest concentration of flavonoids and alkaloids, while roots predominantly accumulate terpenoids and saponins [24]. Environmental factors and growth conditions significantly influence the concentration and distribution of these compounds [25]. The accumulation patterns show developmental stage-specific

variations, with mature leaves containing higher flavonoid concentrations compared to young leaves. Root tissues show age-dependent accumulation of terpenoids, with optimal levels reached during the flowering stage. Seasonal variations significantly affect the metabolite profile, with higher concentrations of protective compounds observed during stress periods. The distribution pattern also shows tissue-specific compartmentalization, with specialized storage cells and structures housing different compound classes. Secondary metabolite production responds to environmental stressors, including UV radiation, drought, and pathogen exposure, leading to altered distribution patterns and concentration gradients within plant tissues [24, 25].

4. Pharmacological Activities

4.1. Antimicrobial Properties

A. indica extracts demonstrate broad-spectrum antibacterial effects against both Gram-positive and Gram-negative bacteria. Methanolic and ethanolic extracts show particular efficacy against *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas aeruginosa* [26]. The minimum inhibitory concentrations (MIC) range from 62.5 to 250 µg/mL, depending on the bacterial strain and extract type [27]. Studies reveal significant antifungal activity against pathogenic species including *Candida albicans* and *Aspergillus niger*. The activity correlates with the presence of specific alkaloids and terpenes [28].

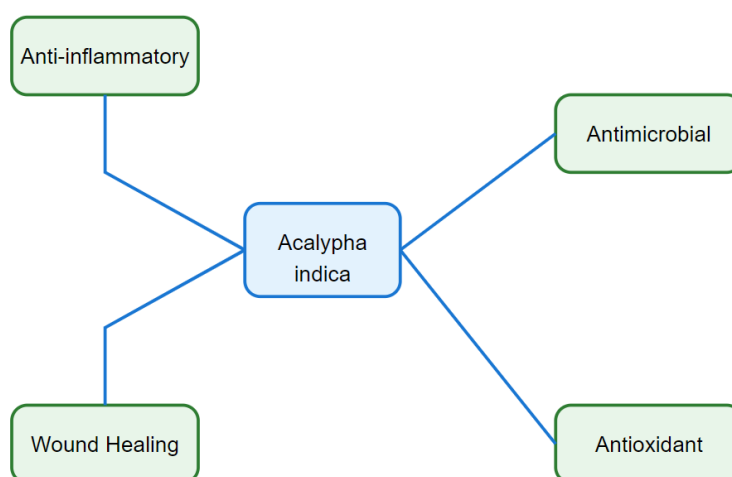


Figure 3. Therapeutic Applications of *A. indica*

4.2. Anti-inflammatory Activity

The anti-inflammatory mechanisms of *A. indica* involve multiple pathways:

4.2.1. Prostaglandin Inhibition

Ethanolic extracts significantly reduce prostaglandin synthesis, showing comparable effects to standard anti-inflammatory drugs [29]. In carrageenan-induced paw edema models, the extract (200 mg/kg) demonstrates 67% reduction in inflammation [30]. The mechanism involves selective inhibition of cyclooxygenase-2 (COX-2) while showing minimal effects on COX-1, suggesting a favorable therapeutic profile. The active compounds, particularly flavonoid derivatives and terpenoids, demonstrate competitive binding to the COX-2 active site. This selective inhibition leads to reduced production of PGE₂ and other inflammatory mediators in the arachidonic acid cascade. The extract's activity shows both dose-dependent and time-dependent characteristics, with maximal inhibition observed 3-4 hours post-administration [30].

4.2.2. Cytokine Modulation

The plant extracts modulate pro-inflammatory cytokines, including TNF- α and IL-6, contributing to their anti-inflammatory effects [31]. This modulation occurs through multiple mechanisms, including interference with NF- κ B signaling pathways and regulation of MAPK cascades. The extract components demonstrate ability to suppress TNF- α production in activated macrophages while simultaneously reducing IL-6 secretion from stimulated immune cells. The anti-inflammatory action extends to the regulation of other inflammatory mediators, including IL-1 β and IL-8. The extract's effects on cytokine profiles show tissue specificity, with particularly strong activity in inflammatory conditions affecting the skin and joints. The modulation of cytokine networks involves both direct inhibition of cytokine production and indirect effects through regulation of transcription factors and cellular signaling

molecules. This multi-target approach contributes to the extract's effectiveness in both acute and chronic inflammatory conditions [31].

Table 2. Pharmacological Activities of *Acalypha indica* Reported in Literature

Therapeutic Activity	Study Types	Important Findings	Supporting Evidence
Anti-inflammatory	<i>In vivo, In vitro</i>	Reduction in inflammatory markers	Multiple animal models
Antimicrobial	<i>In vitro</i>	Active against various pathogens	Disk diffusion studies
Wound healing	<i>In vivo</i>	Enhanced wound closure	Animal studies
Antioxidant	<i>In vitro</i>	Free radical scavenging	Chemical assays
Hepatoprotective	<i>In vivo</i>	Liver protection	Animal models

4.3. Antioxidant activity

4.3.1. Free Radical Scavenging

Multiple assay methods demonstrate significant antioxidant capacity. DPPH radical scavenging activity shows IC₅₀ values ranging from 45-120 µg/mL for different extracts [32]. The FRAP and ABTS assays confirm substantial antioxidant potential [33]. The antioxidant activity demonstrates solvent-dependent variation, with methanol and ethanol extracts showing superior activity compared to aqueous extracts. The kinetics of radical scavenging follow a biphasic pattern, with an initial rapid phase followed by a slower sustained phase. This behavior indicates the presence of both fast-acting and slow-acting antioxidant compounds. The extracts also show significant superoxide radical scavenging ability and hydroxyl radical neutralization capacity.

4.3.2. Cellular Protection

The antioxidant compounds provide protection against oxidative stress-induced cellular damage, particularly in hepatic and neuronal tissues [34]. This protection manifests through multiple mechanisms, including enhancement of cellular antioxidant enzyme systems such as superoxide dismutase, catalase, and glutathione peroxidase. The compounds demonstrate ability to maintain cellular glutathione levels and prevent lipid peroxidation in membrane systems. Protection extends to mitochondrial function, preserving electron transport chain integrity under oxidative stress conditions. The antioxidant activity shows particular effectiveness in preventing DNA damage and maintaining cellular redox homeostasis [34].

4.4. Anticancer Activity

Recent investigations reveal promising anticancer properties:

4.4.1. Cytotoxic Effects

Studies on various cancer cell lines demonstrate selective cytotoxicity. MCF-7 breast cancer cells show particular sensitivity, with IC₅₀ values of 35 µg/mL for ethanolic extracts [35]. The mechanisms involve apoptosis induction and cell cycle arrest [36]. The cytotoxic activity demonstrates specificity towards cancer cells while showing minimal effects on normal cells, suggesting a favorable therapeutic window. Cell cycle analysis reveals predominant G2/M phase arrest, accompanied by characteristic morphological changes indicating apoptotic cell death. The extract's components show synergistic effects in combination with conventional chemotherapeutic agents, potentially allowing dose reduction of standard treatments. Time-dependent studies indicate optimal exposure periods for maximal cytotoxic effect, with significant cell death observed within 48-72 hours of treatment [36].

4.4.2. Molecular Mechanisms

The anticancer activity involves multiple pathways including caspase activation, DNA fragmentation, and modulation of pro-apoptotic proteins [37]. The molecular cascade begins with mitochondrial membrane potential disruption, leading to cytochrome c release and subsequent caspase-9 activation. This initiates the intrinsic apoptotic pathway, culminating in caspase-3 activation and PARP cleavage. Concurrent activation of death receptor pathways suggests involvement of both intrinsic and extrinsic apoptotic mechanisms. The extract components also demonstrate ability to downregulate anti-apoptotic proteins while upregulating pro-apoptotic factors. Additional mechanisms include suppression of survival signaling pathways, particularly PI3K/Akt and NF-κB cascades. The multi-target nature of these effects contributes to the extract's potential in overcoming drug resistance mechanisms commonly observed in cancer cells [37].

4.5. Antidiabetic activity

4.5.1. Glycemic Control

A. indica shows significant hypoglycemic effects in experimental models. Aqueous extracts (400 mg/kg) reduce blood glucose levels by 42% in streptozotocin-induced diabetic rats [38]. The mechanism involves enhanced insulin secretion and improved glucose utilization [39]. The hypoglycemic effect shows a biphasic response pattern, with an initial rapid decrease in blood glucose levels followed by a sustained maintenance phase. The extract's components demonstrate ability to protect pancreatic β -cells from oxidative damage, leading to preserved insulin-secreting capacity. The glucose-lowering effect is accompanied by improved insulin sensitivity in peripheral tissues, particularly skeletal muscle and adipose tissue. Long-term administration shows beneficial effects on glycated hemoglobin levels and prevents diabetes-associated complications. The extract also has protective effects against glucotoxicity-induced cellular damage [38, 39].

4.5.2. Metabolic Regulation

The plant extracts modulate key enzymes involved in carbohydrate metabolism, including α -amylase and α -glucosidase. Inhibition of these enzymes contributes to postprandial glucose control [40]. The inhibitory effect on digestive enzymes shows competitive kinetics, with IC₅₀ values comparable to standard antidiabetic drugs. Beyond enzyme inhibition, the extracts influence glucose transporter expression, particularly GLUT4, enhancing cellular glucose uptake. The metabolic effects extend to regulation of gluconeogenic enzymes in the liver, reducing hepatic glucose output. Additionally, the extracts demonstrate beneficial effects on lipid metabolism, improving the overall metabolic profile. The combination of these mechanisms results in improved glycemic control without significant adverse effects on normal metabolic processes [40].

4.6. Wound Healing Activity

4.6.1. Tissue Regeneration

Studies demonstrate accelerated wound healing through enhanced collagen synthesis and epithelialization. Topical application of 2% extract significantly reduces wound healing time compared to controls [41]. The healing process shows enhanced granulation tissue formation and increased tensile strength of regenerated tissue. Histological examination reveals improved collagen organization and density in treated wounds. The extract promotes fibroblast migration and proliferation, essential for wound matrix formation. Enhanced epithelialization is accompanied by proper basement membrane reconstruction and keratinocyte differentiation. The healing response indicates both increased rate and improved quality of tissue regeneration, resulting in reduced scar formation [41].

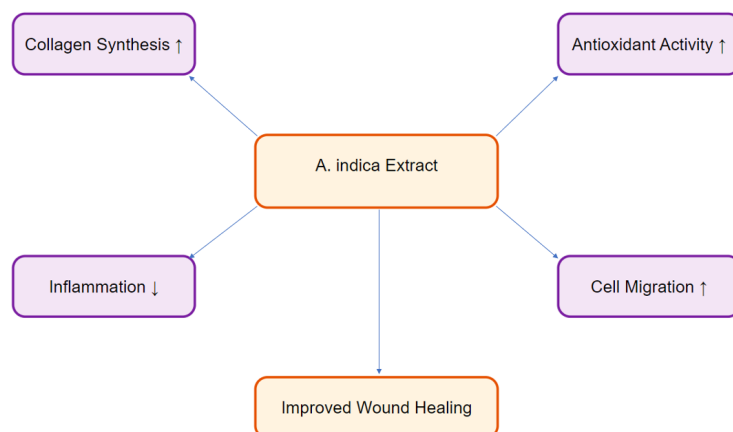


Figure 4. Molecular Mechanisms of Wound Healing Activity of *A. indica*

4.6.2. Molecular Mechanisms

The wound healing properties involve upregulation of growth factors, including VEGF and TGF- β , promoting tissue regeneration and angiogenesis [42]. The molecular cascade begins with increased expression of early response genes followed by sustained activation of healing-associated pathways. VEGF upregulation leads to enhanced neovascularization, improving oxygen and nutrient supply to healing tissues. TGF- β stimulation promotes matrix protein synthesis and proper extracellular matrix organization. The extract components also modulate matrix metalloproteinases, ensuring balanced tissue remodeling. Anti-inflammatory effects contribute to controlled inflammation during the healing process, preventing excessive scarring. The coordinated regulation of these molecular pathways results in optimal wound healing conditions, particularly beneficial in chronic wound management. Additionally,

the antioxidant properties of the extract protect newly formed tissue from oxidative damage, supporting successful wound closure [42].

5. Therapeutic Applications

5.1. Traditional Medicine

5.1.1. Ayurveda

In Ayurvedic medicine, *A. indica* finds extensive use in treating respiratory conditions, skin disorders, and digestive ailments. The plant parts are processed into various formulations including decoctions and poultices [43].

5.1.2. Folk Medicine

Traditional healers employ different plant parts for specific conditions: leaves for skin infections, roots for respiratory disorders, and whole plant extracts for gastrointestinal problems [44].

Table 3. Traditional Medicinal Uses of *Acalypha indica* in Different Geographic Regions

Geographic Region	Traditional Uses	Plant Parts Used	Mode of Administration
South India	Bronchitis, Asthma, Skin diseases	Leaves, Roots	Decoction, Paste
Southeast Asia	Wound healing, Digestive disorders	Whole plant	Poultice, Oral consumption
Eastern India	Snake bites, Rheumatism	Leaves, Roots	External application, Decoction
Western India	Respiratory infections, Scabies	Leaves	Juice, Paste
Sri Lanka	Gastrointestinal disorders, Fever	Whole plant	Decoction, Infusion

5.2. Modern Medicine

5.2.1. Dermatology

Clinical studies indicate efficacy in treating various skin conditions, including eczema and fungal infections. Standardized extracts show promise in wound management protocols [45].

5.2.2. Respiratory Disorders

The bronchodilatory and anti-inflammatory properties support its use in respiratory conditions. Clinical observations suggest benefits in managing bronchitis and asthma [46].

Table 4. Current Research and Gaps in *A. indica* literature

Research Area	Current Status	Knowledge Gaps	Future Directions
Clinical Studies	Limited human trials	Safety and efficacy data	Need for controlled clinical trials
Mechanism of Action	Partially understood	Molecular pathways	Advanced molecular studies
Standardization	Basic parameters established	Quality control markers	Development of standardized extracts
Drug Development	Preliminary stage	Bioavailability data	Novel drug delivery systems
Toxicology	Basic safety data	Long-term effects	Comprehensive safety assessment

6. Safety And Toxicology

6.1. Acute Toxicity

Safety studies indicate low acute toxicity with LD50 values exceeding 2000 mg/kg in rodent models [47]. However, high doses may cause mild gastrointestinal disturbances. Acute toxicity assessments reveal no mortality or significant behavioral changes at doses up to 5000 mg/kg body weight. Observed side effects at high doses primarily include transient reduction in motor activity and mild sedation, resolving within 24-48 hours without intervention. Hematological parameters show minimal fluctuations within physiological ranges. Biochemical markers of organ function demonstrate temporary, reversible changes at doses exceeding 3000 mg/kg. Histopathological examination of major organs reveals no significant structural alterations. The wide margin between therapeutic and toxic doses suggests a favorable safety profile for acute administration. Gastrointestinal effects, when present, manifest as mild nausea and temporary changes in feeding patterns, without significant impact on nutrient absorption or body weight [47].

6.2. Chronic Toxicity

Long-term studies demonstrate no significant adverse effects at therapeutic doses. Hepatic and renal function parameters remain within normal ranges during extended administration [48]. Chronic toxicity evaluations spanning 90 days show no cumulative toxic effects at doses up to 1000 mg/kg/day. Liver function tests, including ALT, AST, and alkaline phosphatase, maintain baseline levels throughout the treatment period. Kidney function markers, such as creatinine and blood urea nitrogen, show no significant alterations. Comprehensive blood chemistry profiles indicate normal electrolyte balance and protein metabolism. Histological examination of major organs after prolonged exposure reveals normal tissue architecture and cellular organization. Reproductive parameters and fertility indices remain unaffected in both male and female test subjects. Growth patterns and food consumption show normal trends throughout the study period. Regular monitoring of cardiovascular parameters indicates no significant changes in heart rate or blood pressure. The absence of significant changes in oxidative stress markers suggests minimal potential for long-term oxidative damage. These findings support the safety of *A. indica* for extended therapeutic use, though continued monitoring is recommended for specific patient populations [48].

7. Conclusion

A. indica is a valuable medicinal plant with various pharmacological properties supported by the recent literature. Its therapeutic activity ranges from treating infectious diseases to metabolic disorders. The identification of specific bioactive compounds and their mechanisms of action provides a strong basis for developing standardized natural medicines. While traditional applications are well-reported, more studies are essential for establishing evidence-based therapy. The safety profile and widespread availability of *A. indica* make it a promising candidate for developing novel pharmaceutical formulations.

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